

PB-229 795

UPPER POTOMAC ESTUARY EUTROPHICATION
CONTROL REQUIREMENTS

Norbert A. Jaworski, et al

Environmental Protection Agency
Annapolis, Maryland

April 1972

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PB.229795

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Prepared for presentation at the 44th Annual Conference of the Water Pollution Control Federation which was held October 3-8, 1971, San Francisco, California.

UPPER POTOMAC ESTUARY
EUTROPHICATION CONTROL REQUIREMENTS

By

Norbert A. Jaworski¹

Leo J. Clark²

Kenneth D. Feigner³

Technical Report 53

April 1972

¹ Jaworski, Dr. Norbert A., Chief, Grosse Ile Field Site, EPA, Office of Research and Monitoring, 9311 Groh Road, Grosse Ile, Michigan 48138

² Clark, Leo J., Chief, Engineering Section, Annapolis Field Office, EPA, Annapolis Science Center, Annapolis, Maryland 21401

³ Feigner, Kenneth D., Sanitary Engineer, EPA, Office of Water Programs, Systems Analysis and Economics Branch, Washington, D. C. 20242

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INTRODUCTION

Based on studies by the U. S. Public Health Service beginning in 1965, the conferees of the Potomac River-Washington Metropolitan Area Enforcement Conference agreed on May 8, 1969, to limit the amount of biochemical oxygen demand, phosphorus, and nitrogen which could be discharged into the Upper Potomac Estuary from wastewater treatment facilities. The conferees recognized a need, not only for high degrees of wastewater treatment for the reduction of carbonaceous and nitrogenous oxygen demanding material, but also a need, for the control of eutrophication.

Additional detailed studies by the Chesapeake Technical Support Laboratory (CTSL)* of the Federal Water Quality Administration** to further define the interrelationships among wastewater inflow, freshwater inflow, and water quality in the Potomac Estuary were undertaken in November 1969. These studies had two purposes: (1) to refine the allowable oxygen demanding and nutrient loadings previously established and (2) to determine the feasibility of using the estuary as a municipal water supply source.

Presented herein is a summary of numerous reports published by CTSL with major emphasis on the eutrophication control aspects developed in the recent studies.

* Now the Annapolis Field Office

** Now the Environmental Protection Agency

BRIEF DESCRIPTION OF THE STUDY AREA

The Potomac River Basin, with a drainage area of approximately 38,000 square kilometers (km^2), is the second largest watershed in the Middle Atlantic States. From its headwaters on the eastern slope of the Appalachian Mountains, the Potomac flows first northeasterly and then generally southeasterly some 644 km, flowing past the Nation's capital. The Potomac is tidal from Washington, D. C., to its confluence with the Chesapeake Bay, a distance of 183 km (Figure 1).

The study area includes the tidal portion, which is about 60 meters (m) in width at its uppermost reach near Washington and broadens to nearly 10 km at its mouth. Except for a 7.5 m shipping channel and a few reaches where depths up to 30 m can be found, the tidal portion is relatively shallow with an average depth of approximately 5.5 m.

Of the 3.3 million people living in the entire basin, approximately 2.8 million reside in the upper portion of the Potomac Estuary within the 7,300 km^2 which comprises the Washington Metropolitan Area. The lower area of the tidal portion, which drains 8,300 km^2 , is sparsely populated.

The upper reach above Indian Head, although tidal, is essentially fresh water. The middle reach is normally the transition zone from fresh to brackish water. The lower reach is mesohaline with chloride concentrations near the Chesapeake Bay ranging from approximately 7,000 to 11,000 mg/l.

The average freshwater flow of the Potomac River near Washington, before diversions for municipal water supply, is 305 cubic meters per second (cms) with a median flow of 185 cms. The flow of the Potomac is virtually unregulated and is thus characterized by extremely high and flashy flows often approaching 2,500 cms during flood conditions and 30 cms during droughts.

WATER QUALITY PROBLEMS

Early historical observations of the water quality conditions include reports that in the late 1790's President Adams swam in the Potomac Estuary near Washington, D. C. By the 1860's when Abraham Lincoln was president, the canals leading into the Potomac Estuary, as well as the Potomac Estuary itself, often emitted objectionable sewage odors forcing Mr. Lincoln to leave the White House at night. From the year 1870, when the first sewers and culverts were constructed, to the year 1938, when the first primary treatment plant was built, almost all of the sewage from the Washington Metropolitan Area was discharged untreated into the Potomac Estuary.

The burgeoning population growth in the Washington Metropolitan Area has compounded the water quality management problem. The accelerated population growth has completely outstripped attempts to provide adequate facilities for wastewater treatment. In addition, much of the growth has been uncontrolled in nature and location, and it is now difficult to provide adequate wastewater collection and treatment within the limited space available for such facilities in the area. Changes in composition of the wastewater, mainly in the phosphorus content, have also had a pronounced effect on water quality.

Since the first sanitary survey was made by the U. S. Public Health Service in 1913 [1], the water quality with respect to bacterial densities and dissolved oxygen levels in the Washington Metropolitan Area has been degraded as a result of the discharge of either untreated or inadequately treated municipal sewage.

The upper estuary has been divided into four reaches according to type and source of pollution as itemized in Table 1 and shown in Figure 2. There are about 90 kilometers of the upper estuary degraded with the effects of eutrophication being pronounced in approximately 50 kilometers. In addition, the Upper Potomac Estuary, including the Anacostia Tidal River, is subjected to periods of high concentrations of sediment.

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Table 1
WATER QUALITY PROBLEMS
Upper Potomac Estuary

Reach	Kilometers of River Affected	Major Type of Pollution	Major Source of Pollution
Chain Bridge to Hains Point	11	Frequently high bacterial counts	Overloaded sanitary sewers and combined sewer overflows
Hains Point to Piscataway Creek	16	Low-dissolved oxygen concen- trations	Effluents from wastewater treatment facilities
Piscataway Creek to Maryland Point	50	Nuisance algal growths	Nutrients in waste- water discharges
Anacostia Tidal River	13	Frequently high bacterial counts and low-dissolved oxygen concen- trations	Combined and sanitary sewer overflows

During initial studies of the estuary, major emphasis was placed on the high bacterial and low-dissolved oxygen problems [2] [3]. More recently, the nuisance algal problem has also been included.

The time frame of algal problem development has been developed from several studies as summarized by Jaworski et al. [4]. As shown in Figure 3, there have been historical invasions of nuisance growths in the Upper Potomac Estuary.

From a review of data in Figure 3, it would appear that nuisance conditions did not develop linearly with an increase in nutrients. Instead, the increase in nutrients appeared to favor the growth and eventually the domination by a given species. As nutrients increased further, the species in turn was rapidly replaced by another dominant form. For example, water chestnut was replaced by water milfoil which in turn was replaced by blue-green algae, mainly Anacystis.

The massive blue-green algal blooms, which have occurred every summer since 1960, appear to be associated with large increases in phosphorus and nitrogen loadings in the upper reaches of the Potomac River tidal system (Figure 3). The blooms have persisted since the early 1960's although during this period the amount of organic carbon from wastewater was reduced by almost 50 percent when compared to that discharged prior to 1960.

Under warm temperature and low-flow conditions, large standing crops of this alga develop forming green mats of cells. Chlorophyll a concentrations range from approximately 50 to over 200 $\mu\text{g/l}$ in these areas of

dense growth which at times extends over approximately 80 km of the upper and middle reaches of the estuary. These high chlorophyll levels are 5 to 10 times those reportedly observed in other eutrophic waters by Brezanik et al. [5] and by Welch [6]. During a dense bloom, the dry weight of cells ranges from 10 to 25 mg/l which is almost twice those reported for the lakes in Madison, Wisconsin.

In the mesohaline portion of the lower reach of the Potomac Estuary, the algal populations are not as dense as in the freshwater portion. Nevertheless, at times large populations of marine phytoplankton (primarily the dinoflagellates Gymnodinium sp. and Amphidinium sp.) occur producing what are known as "red tides."

NUTRIENT CONCENTRATIONS AND SOURCES

The concentration of nutrients along the estuary varies as a function of wastewater loading, temperature, freshwater inflow from the upper basin, biological activity, and salinity. The annual distribution of the various nutrient concentrations has been reported by Jaworski et al. [4], and the summer levels are summarized in Table 2 for five key stations along the estuary.

In the vicinity of the Woodrow Wilson Bridge, there is an increase in alkalinity, total phosphorus, $\text{NO}_2 + \text{NO}_3$ nitrogen, and ammonia nitrogen with a corresponding decrease in pH, all of which can be attributed to the 1230 million liters per day of wastewater discharged in the Washington Metropolitan Area. The rapid disappearance of the ammonia nitrogen between Woodrow Wilson Bridge and Indian Head is caused by the oxidation of NH_3 to $\text{NO}_2 + \text{NO}_3$ by the nitrifying bacteria. The sharp drop in $\text{NO}_2 + \text{NO}_3$ nitrogen between Indian Head and Maryland Point is attributable to the large uptake by the pronounced algal growths in this area.

A complete analysis of the nutrient sources in the Upper Potomac Estuary has been made by Jaworski et al. [4]. A summary of the major sources is presented in Table 3 for low, median, and high Potomac River flows.

Table 2
AVERAGE RANGE OF CONCENTRATION
SUMMER CONDITIONS
Upper Potomac Estuary

Station and Kilometers from Chain Bridge	pH (units)	Alkalinity (mg/l)	Total Phosphorus (mg/l)	NO ₂ + NO ₃ Nitrogen (mg/l)	NH ₃ Nitrogen (mg/l)
Chain Bridge (0.0)	7.5 - 8.0	80 - 100	0.08 - 0.20	0.3 - 1.0	0.10 - 0.50
W. Wilson Bridge (19.5)	7.0 - 7.5	90 - 110	0.30 - 1.20	0.8 - 1.2	1.00 - 3.00
Indian Head (49.3)	7.2 - 8.0	70 - 90	0.20 - 0.40	0.5 - 1.5	0.10 - 0.50
Maryland Point (84.3)	7.5 - 8.2	60 - 85	0.10 - 0.25	0.1 - 0.3	0.05 - 0.30
301 Bridge (104.7)	7.5 - 8.0	65 - 85	0.05 - 0.20	0.1 - 0.2	0.05 - 0.20

Table 3

SUMMARY OF MAJOR NUTRIENT SOURCES
Upper and Middle Reaches of the Potomac Estuary

Low-flow Conditions
(95 % of time exceeded)

(Potomac River Discharge at Washington, D. C. = 40 cubic meters/sec)

	Upper Basin Runoff* (kg/day)	Percent of Total	Estuarine Wastewater Discharges (kg/day)	Percent of Total	Total (kg/day)
Carbon	77,100	52	72,600	48	148,700
Nitrogen	3,000	10	27,200	90	30,200
Phosphorus	450	4	10,900	96	11,350

Median-flow Conditions
(50 % of time exceeded)

(Potomac River Discharge at Washington, D. C. = 185 cubic meters/sec)

Carbon	159,000	68	72,600	32	231,600
Nitrogen	18,100	40	27,200	60	45,300
Phosphorus	2,400	18	10,900	82	13,300

High-flow Conditions
(5 % of time exceeded)

(Potomac River Discharge at Washington, D. C. = 1150 cubic meters/sec)

Carbon	680,000	90	72,600	10	752,600
Nitrogen	185,000	87	27,200	13	212,200
Phosphorus	10,000	47	10,900	53	20,900

* Upper basin runoff includes both land runoff and wastewater discharges in upper basin.

When considering only upper basin runoff and wastewater discharges to the estuary as summarized in Table 3, it can be concluded that the order of percentage of nutrients controllable by wastewater treatment is (1) phosphorus, (2) nitrogen, and (3) carbon.

While the controllable phosphorus and nitrogen percentages decrease at higher flows, these conditions usually occur during the months of February, March, and April, when temperatures and algal crops are lowest. Since nuisance algal conditions occur primarily in the upper or the freshwater portion of the estuary, the higher flow effects are reduced considerably by the time the blooms are most prolific during the months of July, August, and September.

Under low- and median-flow conditions, both nitrogen and phosphorus are largely controllable. If allowances are made for atmospheric contributions of nitrogen, only an approximate 2200 kg/day of nitrogen could be added to the upper estuary, which is less than 10 percent of the nitrogen in the wastewater discharges. Thus, during summer months, algal control by management of nitrogen instead of phosphorus appears to be a feasible alternative.

Using only 0.1 percent of the transfer rate, the amount of carbon (CO_2) potentially available from the atmosphere was estimated to be approximately 431,000 kg/day [4]. Moreover, with the upper reach of the estuary well mixed due to tidal action, recruitment of carbon from benthic decomposition appears to be a significant source of inorganic carbon as well. When all

potential sources are considered, it appears that management of carbon for algal control is not a feasible alternative at the present time.

EUTROPHICATION CONTROL REQUIREMENTS

For water quality management purposes, the Upper Potomac Estuary may be considered hypereutrophic when nuisance plant organisms become predominant as is now occurring with the blue-green algae. Four major water use interferences have been offered by Jaworski et al. [4] including the desired reduction in the algal standing crop for each of the conditions as shown in Table 4.

The first two are related to the oxygen budget. Studies have demonstrated that during the summer months more ultimate oxygen demand is added to the upper estuary as a result of these algal growths than from the present wastewater discharges, though this demand may not be fully exerted.

The aesthetic and recreational potential of the upper estuary are impaired by the extensive mats of algae which cause objectionable odors, clog marinas, and cover beaches and shorelines. The potential use of the estuary as a water supply source could also be impaired because of possible toxin problems associated with the blue-green algae.

Of the four interferences, the highest reduction percentages are for control of algal growths to prevent nuisance conditions. From the data in Table 4, a 75 to 90 percent reduction in chlorophyll a concentrations will be required to limit chlorophyll levels to approximately 25 $\mu\text{g/l}$, the concentration selected as the desired upper limit for eutrophication control in the Upper Potomac Estuary.

Table 4

SUBJECTIVE ANALYSIS OF ALGAL CONTROL REQUIREMENTS

<u>Water Quality or Water Use Interference</u>	<u>Indications of Interference</u>	<u>Magnitude of Current Interference*</u>	<u>Desired Limit</u>	<u>Required Percentage Reduction of Current Standing Crop</u>
D _O Depression Caused by Algal Respiration	mg/l of D _O Below Saturation	1.5 to 3.0 mg/l	0.5 mg/l	65-85
Increase of Total Oxygen Demanding Load	mg/l of Increase in Ultimate BOD	15 to 30 mg/l	5.0 mg/l	65-80
Recreational & Aesthetic Nuisance Conditions	Chlorophyll <u>a</u> Concentration	100 to > 250 µg/l	25 µg/l**	75-90
Toxins	Undefined	Unknown	Unknown	Unknown

* Under nuisance-bloom conditions, chlorophyll a concentrations range from 100 to >250 µg/l

** Average over entire water column

NUTRIENT CRITERIA

The desired nutrient criteria were developed using data from: (1) algal composition analysis, (2) annual nutrient cycles and longitudinal profiles, (3) bioassay studies, (4) review of historical data, (5) comparison with a noneutrophic estuary, and (6) algal modeling. Each method was used independently in the development of a nutrient phytoplankton relationship in the Potomac Estuary.

When investigating the role of nitrogen and phosphorus in eutrophication of the Potomac Estuary, a detailed study of the movement of these nutrients was made using both a real-time dynamic water quality estuary model [8] and an average tidal mathematical model [9]. The dynamic model was expanded to predict the concentration of chlorophyll a based on the utilization of inorganic nitrogen. In Figure 4, predicted $\text{NO}_2 + \text{NO}_3$, NH_3 , and chlorophyll a profiles are presented. The predicted maximum concentrations conform closely to observed data in both distribution and magnitude.

From field data, bioassay studies, and mathematical model runs, it was concluded that the standing crop of blue-green algae can be predicted using the nitrogen cycle. This further supports the premise that the nitrogen availability appears to control the standing crop. Similar methods also indicated that if total phosphorus were in the range of 0.03 to 0.1 mg/l, the desired 25 $\mu\text{g/l}$ level of chlorophyll could be realized.

Based upon the six independent methods of analysis and the 25 $\mu\text{g/l}$ level of chlorophyll a, the following nutrient criteria were developed for reversing the eutrophication process occurring in the freshwater portion of the Potomac Estuary:

<u>Parameter</u>	<u>Concentration Range</u>
Inorganic Nitrogen	0.30 - 0.5 mg/l
Total Phosphorus	0.03 - 0.1 mg/l

Since there are over 5.0 mg/l of inorganic carbon in the estuary, even under maximum bloom conditions, no criterion for carbon could be established at the present time.

The lower values in these ranges are to be applied to the freshwater portion of the middle reach and to the embayment portions of the estuary in which the environmental conditions are more favorable toward algal growth. The higher values are more applicable to the upper reach of the Potomac Estuary which has a light-limited euphotic zone of usually less than 0.60 meters.

Since the growth of massive blue-green algal mats are apparently restricted to the freshwater portions and dinoflagellates are often encountered in the mesohaline environment, no specific nutrient criteria have been established for the mesohaline portion of the Potomac Estuary. It appears that if the aforementioned nutrient criteria are achieved in the upper estuary, adequate control of the eutrophication process in the lower reach of the estuary should also be realized.

WASTEWATER MANAGEMENT ZONES

To facilitate the determination of wastewater management requirements, the upper and middle reaches of the estuary were initially divided into three 15-mile (24 km) zones with similar physical characteristics, beginning at Chain Bridge (see Figure 1). This zoning concept, patterned after the Delaware Estuary, allows for greater flexibility in developing control needs and was adopted by the Conferees at the Potomac Enforcement Progress Meeting on May 8, 1969.

More recent studies in 1970 have suggested that Zone I be divided into three subzones described as follows:

<u>Subzone</u>	<u>Description</u>
I-a	Potomac Estuary from Chain Bridge to Hains Point, a distance of 12.1 kilometers.
I-b	Anacostia tidal river from Bladensburg, Maryland, to the confluence with the Potomac, a distance of 14.4 kilometers.
I-c	Potomac Estuary from Hains Point to Broad Creek, a distance of 12 kilometers.

Discharges into tidal embayments were investigated on an individual basis.

Using the zonal concept, total maximum loadings for each pollutant were developed for each zone. Allocation of pound loadings for each discharge can be obtained by prorating the zonal poundage using various bases such as population, drainage areas, geographical subdivisions, and others.

WATER QUALITY SIMULATION MODELS

Water quality simulations and wastewater treatment investigations were made using the FWQA Dynamic Estuary Model (DEM) and the DECS III, a general purpose estuarine model. The DEM [8] is a real-time system utilizing a two-dimensional network of interconnecting junctions and channels which permits direct inclusion of tidal embayments in the flow representation. The model is comprised of a hydraulic component that describes tidal movement and a quality component. The DEM includes the basic transport mechanisms of advection and dispersion as well as the pertinent sources and sinks for each constituent. This model was used to simulate water quality conditions on an hourly basis and to determine zonal loadings under low-flow conditions.

DECS III is based on a time-dependent tidal average solution of the basic mass balance equations [9]. This model was used to investigate seasonal variations in the nitrogen and phosphorus distributions in the Upper Potomac Estuary.

The interrelationship between ultimate oxygen demand* (UOD) loadings and dissolved oxygen (DO) in the Potomac Estuary was determined assuming the following conditions:

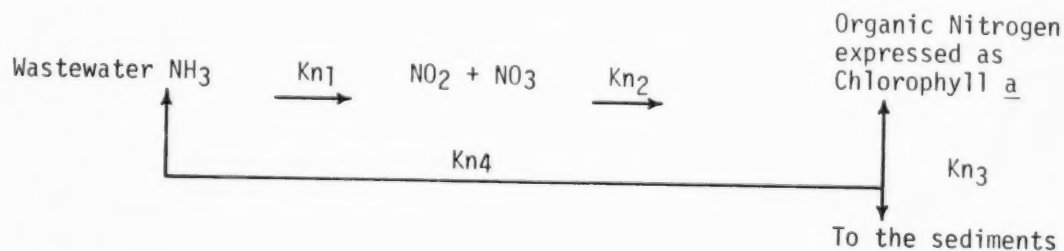
<u>Parameter</u>	<u>Value</u>
Water Temperature	29.0°C
Freshwater inflow from upper Potomac River Basin	10.0 CMS
DO standard (average)	5.0 mg/l
DO saturation at 29°C	7.7 mg/l
Background DO deficit	0.7 mg/l
Allowable DO Deficit	2.0 mg/l

* The ultimate oxygen demand represents the sum of unoxidized carbon and nitrogen

In the DO model, the oxidation of carbonaceous and nitrogenous fractions, including the reaction kinetics, were formulated separately.

Simulation of phosphorus discharges into the Potomac Estuary was made using second-order reaction kinetics with a deposition rate of 0.05 mg/day at a temperature of 29°C. The allowable phosphorus loadings were determined based on maintaining an average of 0.1 mg/l of phosphorus (P) within Zone I, 0.067 mg/l (P) within Zone II, and 0.03 mg/l (P) within Zone III.

For investigating the role of nitrogen in water quality management, a feedback system of the nitrogen cycle was incorporated into the dynamic estuary mathematical model similar to that proposed by Thomann et al. [10]. The model consists of six possible reactions: (1) chemical and biological decomposition of organic nitrogen to ammonia, (2) bacterial nitrification of ammonia to nitrite and nitrate, (3) phytoplankton utilization of ammonia, (4) phytoplankton utilization of nitrite and nitrate, (5) deposition of organic nitrogen, and (6) decay of phytoplankton. With the area near Woodrow Wilson Bridge being light limiting with respect to algal growth, the utilization of ammonia by phytoplankton appears to be insignificant and thus the model was simplified as given below:



For summer temperatures of 26°C to 29°C, first-order kinetic reaction rates have been established for the various processes as given below:

Nitrification by bacteria (K_{n1})	0.30 to 0.40
Nitrogen utilization by phytoplankton (K_{n2})	0.07 to 0.09
Deposition of algal cells (K_{n3})	0.005 to 0.05
Remineralization (K_{n4})	(less than 0.05)

The reaction rates of the first two processes (nitrification and nitrogen utilization) have been well established as demonstrated in the profile shown in Figure 3. The latter two, K_{n3} and K_{n4} , although not as well defined, do not appear to be as significant. The nitrogen criteria used for Zones I, II, and III were 0.5, 0.4, and 0.3 mg/l, respectively.

MAXIMUM CONSTITUENT LOADINGS PER ZONE

Using the models and coefficients as described in the previous sections, zonal loadings were determined for UOD, nitrogen, and phosphorus (see Table 5). The loadings presented are maximum allowable loadings for each zone, assuming that adjacent zones are loaded to their maximums.

The increase in loadings for the lower zones mainly reflect the increase in the estuary's volume and tidal transport. Since nitrogen and phosphorus criteria for the lower zones are more stringent, the increase in nutrient loadings in this area is not as pronounced as for UOD.

For the projected 1980 wastewater loading conditions, the anticipated percent removal rates for Zone I-c would be approximately 93 percent UOD, 96 percent phosphorus and 93 percent nitrogen. Since Zones II and III do not currently receive as much wastewater, the removal percentages will not be as high.

SEASONAL WASTE TREATMENT REQUIREMENTS

1. Ultimate Oxygen Demand

The maximum allowable UOD loadings, as presented in Table 5 for the three upper zones of the Potomac Estuary, were developed for low-flow and summer temperature conditions. During high temperature periods, the effects of nitrogenous oxygen demanding substances on the dissolved oxygen budget were determined to be quite significant.

Studies have shown that during very warm periods, when nitrification rates are high, the nitrogenous component of UOD exerts 250,000 lbs/day of oxygen demand as compared to approximately 200,000 lbs/day from the carbonaceous demand. During low temperature periods, when the ambient water temperature is less than 15°C, the effects of nitrification on the dissolved oxygen budget have been shown to be negligible.

Based on these findings, it was recommended that (1) UOD loadings presented in Table 5 be applied only under summer conditions, (2) the removal or oxidation of ammonia in wastewater discharges be provided whenever the water temperature is above 15°C, and (3) a high degree of removal of suspended solids (a maximum of 15 mg/l in the effluent) and carbonaceous oxygen demanding material (a minimum of 90 percent) be provided on a year-round basis to prevent the accumulation of sludge deposits in the vicinity of sewage treatment plant outfalls during cooler weather and to maintain high DO levels under ice cover.

Table 5
MAXIMUM UOD, PHOSPHORUS, AND NITROGEN
WASTEWATER LOADINGS
FOR LOW-FLOW SUMMER CONDITIONS
(kg/day)

<u>Zone</u>	<u>Allowable UOD</u>	<u>Phosphorus</u>	<u>Nitrogen</u>
I-a	1,800	90	450
I-b	1,400	40	140
I-c	33,800	400	1,580
II	85,500	680	2,600
III	171,000	900	4,100

2. Phosphorus and Nitrogen

The loadings, as presented in Table 5, were established for low-flow conditions. During these periods, the nutrient contribution from the upper basin is insignificant when compared to that contained in the wastewater discharges.

To determine whether the nitrogen and phosphorus criteria could be met under varying Potomac River inflows and varying nutrient contributions from the upper basin, an annual simulation was made of conditions from February 1969 to September 1970. This period was critical because a drought condition occurred during June and July of 1969, and August flows were over four times above the average discharge. Thus, both low and high summer flows were simulated.

Mathematical model analysis of the annual distribution of phosphorus in the critical algal growing area showed close agreement between the observed and predicted phosphorus profiles (see Figure 5). Also shown in Figure 5 are the predicted annual phosphorus profiles resulting from year-round wastewater phosphorus removal in the upper estuary, assuming: (1) no control and (2) 50 percent control of the phosphorus loading originating in the Upper Potomac River Basin. From the data presented in Figure 5, it was concluded that both (1) the adherence to maximum allowable phosphorus loadings from wastewater effluents being discharged directly into the estuary (see Table 5) and (2) a 50 percent reduction of the total incoming phosphorus load from the upper basin, will be required

if the recommended maximum phosphorus criteria are to be realized. In order to achieve a 50 percent reduction in the present phosphorus load from the Upper Potomac River Basin, the current overall wastewater contribution of 2700 kgs/day must be reduced to less than 320 kgs/day.

Because of the more stringent criteria, particularly in the lower zones including longer transport time, the possibility of recycling previously deposited phosphorus from bottom muds and the unpredictability of phosphorus in various forms being transported from the upper basin, year-round phosphorus removal at all wastewater treatment facilities in the Potomac River Basin was recommended.

As presented earlier, the necessity for unoxidized nitrogen control in wastewater discharges to maintain a high dissolved oxygen content in the Potomac Estuary was restricted to that time of year when water temperatures exceed 15°C. When evaluating the need for annual nitrogen control to prevent excessive algal blooms, controllability, duration of nuisance blooms, and temperature become significant factors.

While spring blooms of diatom algal cells have been observed, the major nuisance blue-green algal blooms of algae usually occur during the months of July, August, and September. During these months, the controllability of nitrogen by wastewater treatment is usually greatest and the water temperature highest.

Mathematical model predictions of inorganic nitrogen concentrations in critical algal growing areas based on (1) no estuary wastewater nitrogen

removal, (2) nitrogen removal during periods with temperatures above 15°C (April-November), and (3) year-round nitrogen removal are presented in Figure 6. For the nitrogen loading as given in Table 5, the inorganic nitrogen concentration of less than 0.3 mg/l can be achieved for drought conditions such as in June and July. The abnormally high August Potomac River flow condition and resulting high upper basin loading caused the nitrogen level to increase to approximately 0.5 mg/l.

While it may be desirable to maintain nitrogen concentrations at or below the selected criteria at all times, the high flows from the upper basin during the winter and spring months contribute high nitrogen loadings which increase the nitrogen concentrations above acceptable levels regardless of wastewater treatment practices. In considering (1) that nuisance algal growths occur mainly during the months of July, August, and September, (2) that seasonal nitrogen removal is generally adequate for maintaining the desired nitrogen concentration during this time, and (3) that unoxidized nitrogen control is required only for warm temperature periods, it was recommended that nitrogen removal for algal control, as in the case of nitrogenous demand for oxygen enhancement, be limited to periods when water temperatures in the estuary exceed 15°C.

In developing the seasonal requirements, emphasis was placed on maintaining a balanced ecological community structure in the upper or freshwater portion of the estuary. More research efforts in both transport mechanisms and nutrient algal relationships are needed to determine management requirements for the lower or saline portion of the estuary.

SELECTION OF UNIT PROCESSES TO ACHIEVE WATER QUALITY OBJECTIVES

The decision, as developed throughout this report as to which nutrient or nutrients in a natural system should be controlled by removal from point sources, may depend upon many factors, including the four listed below:

1. Desired level of nuisance algal reduction,
2. Minimum algal nutrient requirements,
3. Controllability and mobility of a given nutrient, and
4. The overall water quality management needs.

In establishing an overall wastewater management program for the Potomac Estuary, a need for a high degree of removal of wastewater carbonaceous and nitrogenous ultimate oxygen demand was established for maintaining the desired oxygen standards along with a need for a 75-90 percent reduction in algal standing crop. To provide for algal control, maximum concentration limits for both nitrogen and phosphorus were adopted. Concentration limits for both were incorporated for the following reasons:

1. Since the flow of the Potomac River is unregulated and subject to periods of high runoff, neither phosphorus nor nitrogen can be controlled by wastewater removal alone at all times. The advantage of controlling phosphorus or nitrogen depends on the flow conditions.

To reduce eutrophication in the entire estuary for years with average or above average flow conditions, phosphorus control appears to be more feasible. In the middle and upper estuary, nitrogen control is four times

as effective during low-flow years in that the nitrogen criterion for restriction of algal growth is 10 times that for phosphorus (0.30 versus 0.03 mg/l) while the nitrogen loading from wastewater treatment facilities is 2.4 times that of phosphorus (27,200 versus 10,900 kg/day). Since phosphorus control is more advantageous during high flows and nitrogen control more advantageous at low flows, removal of both would be needed to control the nuisance growths effectively.

2. Various investigators have reported that increases in nitrogen and/or phosphorus can increase heterotrophic activity which in turn stimulates algal growth, and

3. There is a compatibility between the wastewater treatment methods to increase dissolved oxygen levels and the methods used to control eutrophication.

Compatibility in treatment requirements is probably one of the most important considerations influencing the selection of wastewater treatment unit processes. For example, in order to achieve and maintain the dissolved oxygen standard in the upper estuary under summer conditions, a high degree of carbonaceous and nitrogenous oxygen demand removal is required, whereas the control of algal standing crops is predicated on phosphorus and nitrogen removal. To obtain a high degree of carbonaceous oxygen demand removal, an additional unit process is usually required beyond secondary treatment. If the proper unit process is selected, it will also remove a high percentage of phosphorus.

The removal of the nitrogenous oxygen demand can be satisfied by one of two methods: (1) by converting the unoxidized nitrogen to nitrates (commonly called nitrification) or (2) by complete removal of nitrogen. If a unit process such as ion exchange or biological nitrification-denitrification is employed, both DO and algal requirements for nitrogen can be met.

Recent chemical analyses of the sediments of the Potomac Estuary indicate high concentrations of heavy metals near the wastewater discharges. Since there are no major industrial waste discharges in the Washington area, the buildup of heavy metals from the municipal discharges could become a future control need in that the lower portion of the estuary is a prime shellfish producing area.

With proper selection of wastewater treatment unit processes, it is feasible to enhance the DO by removing the carbonaceous and nitrogenous UOD. In addition, it is feasible also to reduce nuisance algal growth by removing these nutrients and to reduce the potential hazard of heavy metals.

ESTIMATED COSTS

The present worth cost of providing for additional wastewater flows and treatment requirements from the year 1970 to 2020, including operation, maintenance, and amortization cost, has been estimated to be \$1.34 billion, with a total average annual cost of \$64.8 million. The unit treatment processes assumed include activated sludge, biological nitrification-denitrification, lime clarification, filtration, effluent aeration, and chlorination.

The tabulation below is a reduction of the initial capital and operation and maintenance costs to a per capita basis:

<u>Item</u>	<u>1970-1980</u>	<u>1980-2000</u>	<u>2000-2020</u>
Average Population	3,350,000	5,350,000	8,000,000
Initial Capital Cost/Time Period	\$570,000,000	\$528,000,000	\$1,173,000,000
Capital Cost/Person/Year	\$17.0	\$4.9	\$7.3
O & M Cost/Year	\$25,100,000	\$46,200,000	\$72,400,000
O & M Cost/Person/Year	\$7.5	\$8.6	\$9.1
Total Cost/Person/Year	\$24.5	\$13.5	\$16.4

The above summary, which does include replacement cost, indicates that the cost of wastewater treatment in the Upper Potomac Estuary is about \$13 to \$24/per person/per year. This expenditure, which includes the cost of the activated carbon process, will renovate the water to the chemical and bacteriological levels to meet drinking water quality standards.

MANAGEMENT PLANNING

The current program to control water pollution in the National Capital Region, developed by the 1969 Enforcement Conference, includes a schedule for completion of the needed treatment facility construction. For the major waste discharge in the area, the District of Columbia treatment facility at Blue Plains, progress has been slow.

In the fall of 1970, the parties involved in the Blue Plains problem developed a "Memorandum of Understanding on the Washington Metropolitan Regional Water Pollution Control Plan." This memorandum of understanding was the first formally adopted planning approach to wastewater management in the Washington Metropolitan Area. It recognized that the maximum capacity of the waste treatment facility at Blue Plains should be limited in size and established the basis for financing and cost sharing in the proposed expansion and upgrading of the facility. It also recognized the need for the development of a second regional wastewater treatment facility and a schedule for the development of plans for this facility.

The primary problem to be overcome in achieving the wastewater treatment requirements, as stipulated by the Potomac Enforcement Conference, is financial. The total capital cost of these improvements, if storm and combined sewer control and intercept costs are included, is estimated to be approximately \$857,000,000 for the program through 1980.

The capital cost of nutrient control has been estimated to be about \$250,000,000 or about 28 percent of total wastewater collection and treatment cost. Considering wastewater treatment cost only, the capital cost is

approximately 44 percent with approximately 85 percent of the operating cost for nutrient control.

To aid in managing the water supply and waste treatment problems of the National Capital Region, EPA has proposed the creation of a regional authority [11]. Public hearings are currently being held to give the public, state, and local officials an opportunity to offer their views on the management plan.

SUMMARY

In summary, the needs, costs, and mechanisms for controlling eutrophication in the Potomac Estuary have been identified and a start has been made in implementing the program. With a capital cost for nutrient removal of over \$250,000,000, a need exists for continuous efforts to improve eutrophication control, treatment methods, cost estimates, and institutional arrangements. A need also exists to maintain a free-flowing continuous exchange of information among the various agencies conducting the removal requirement studies, designing the facilities, and planning the overall management needs. These interactions are the keystones to successful management planning.

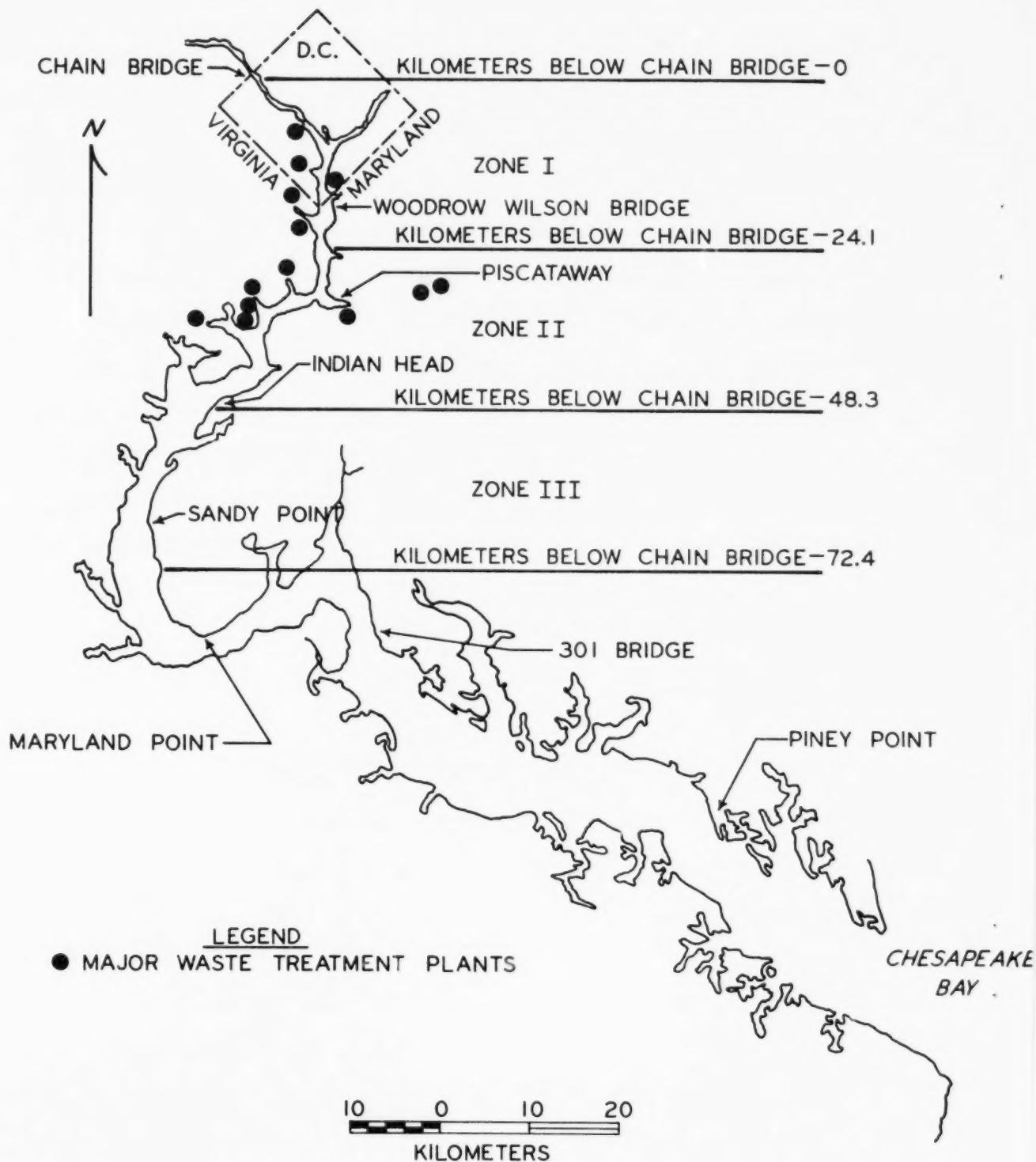


Figure 1

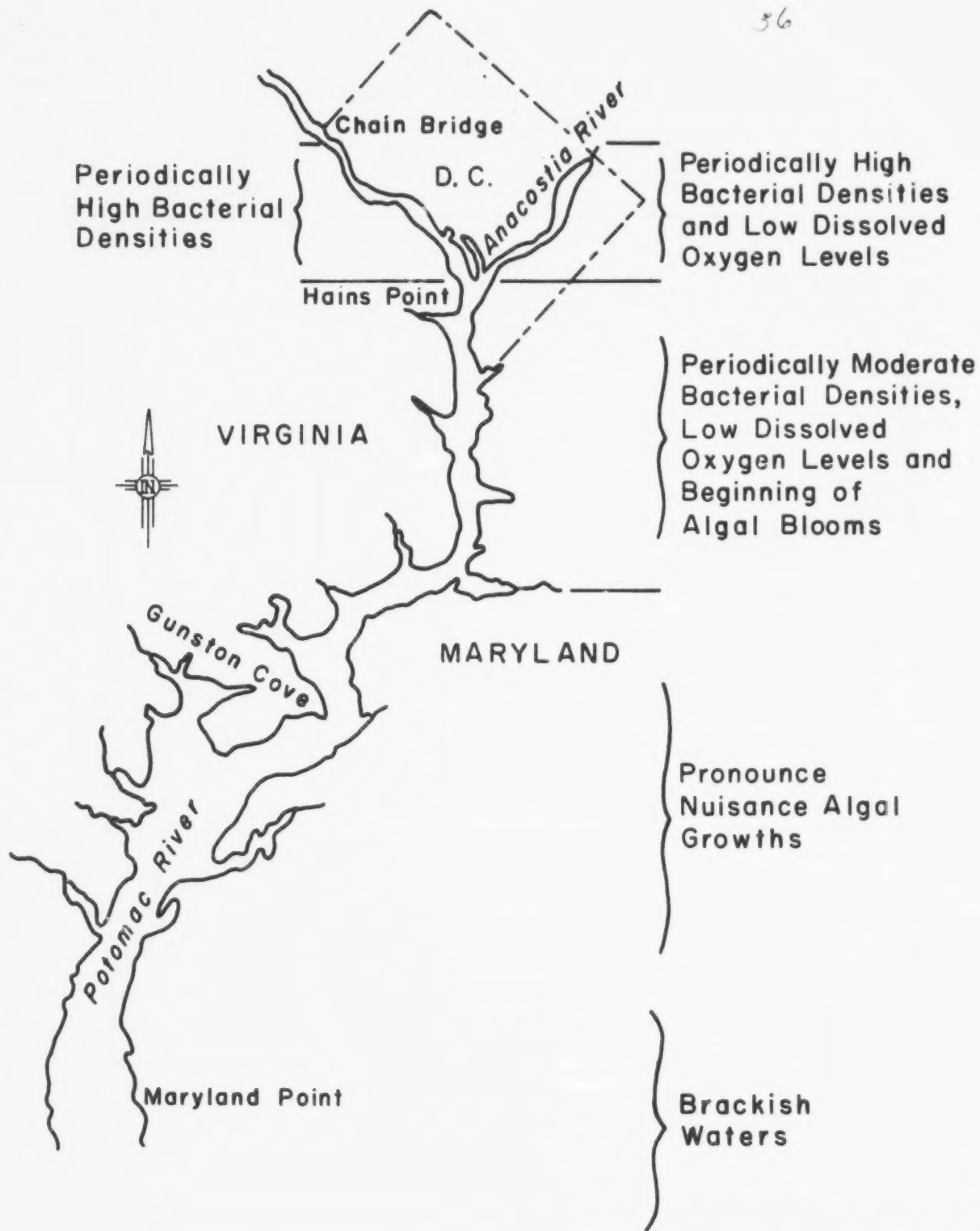


Figure 2

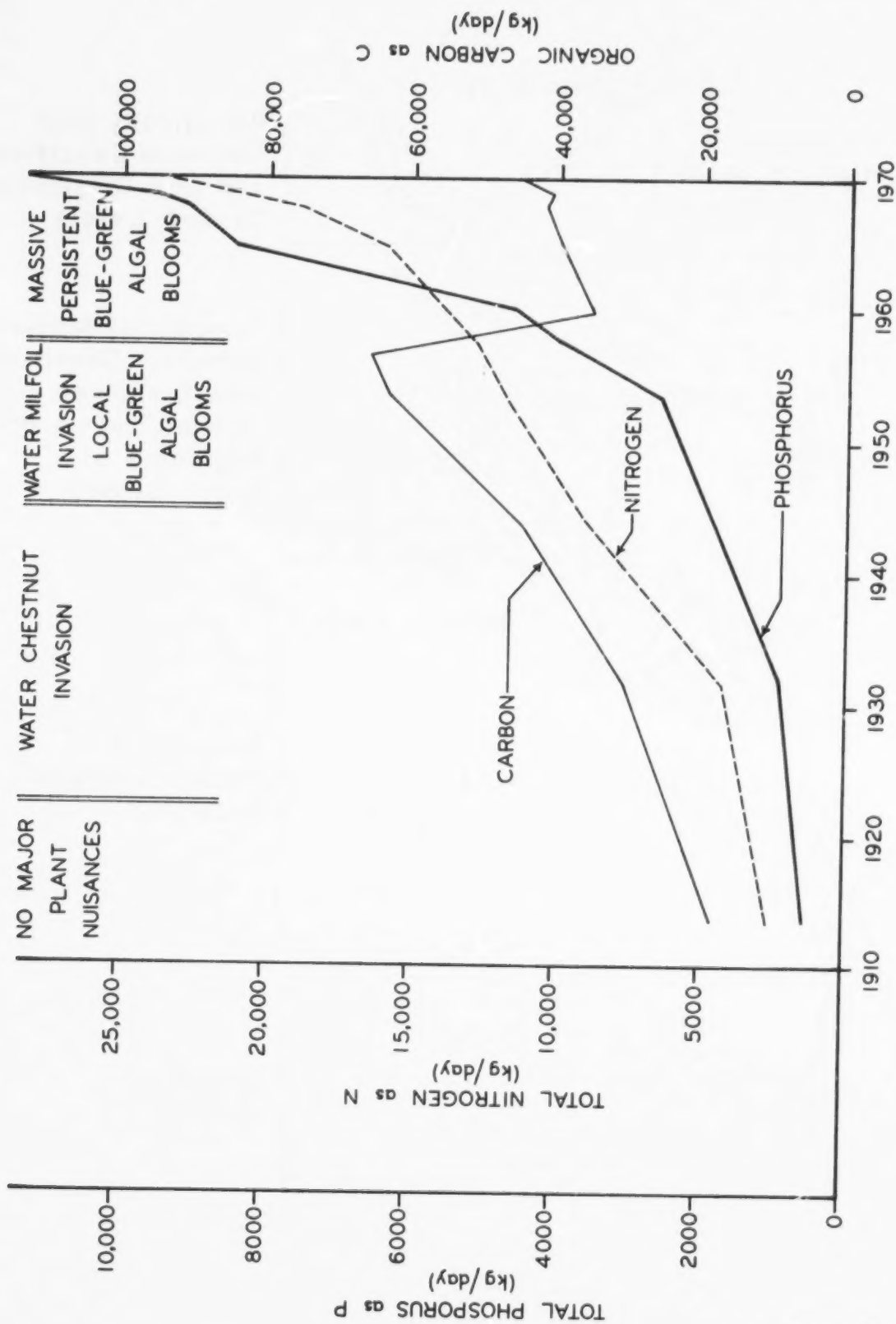
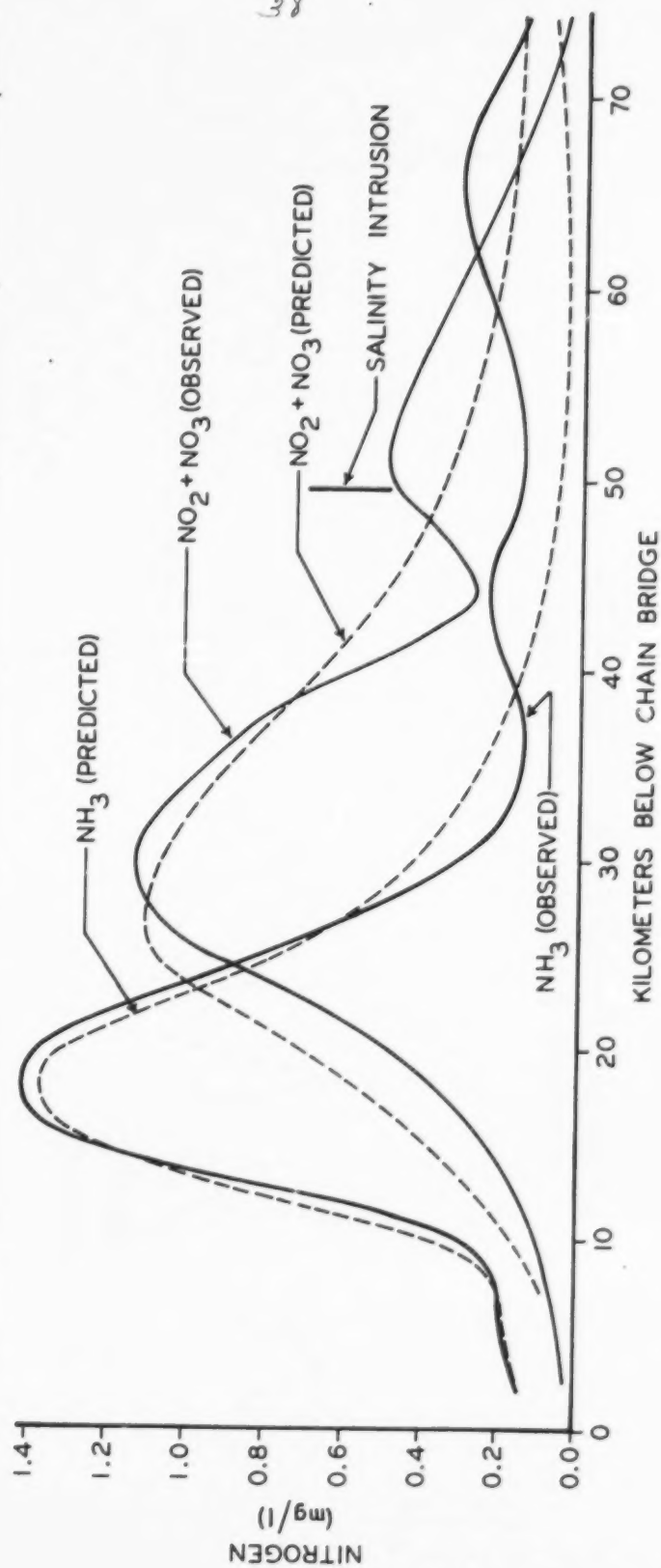
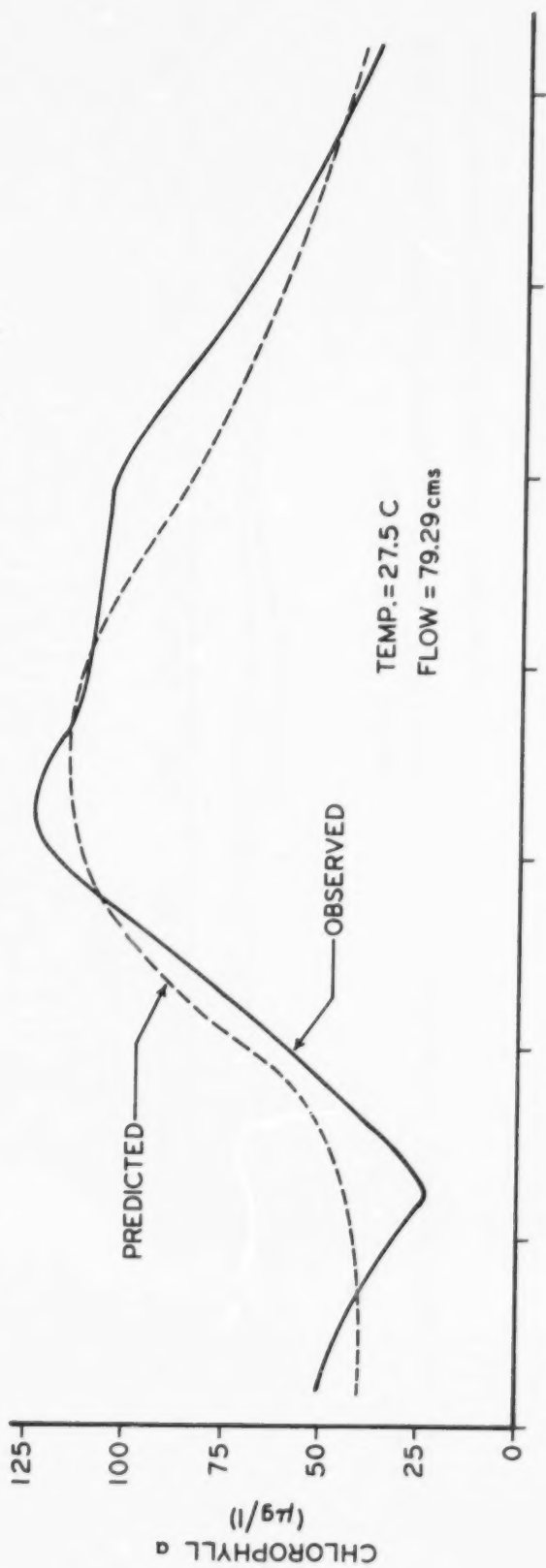


Figure 3



ANNUAL PHOSPHORUS PROFILES POTOMAC ESTUARY AT INDIAN HEAD

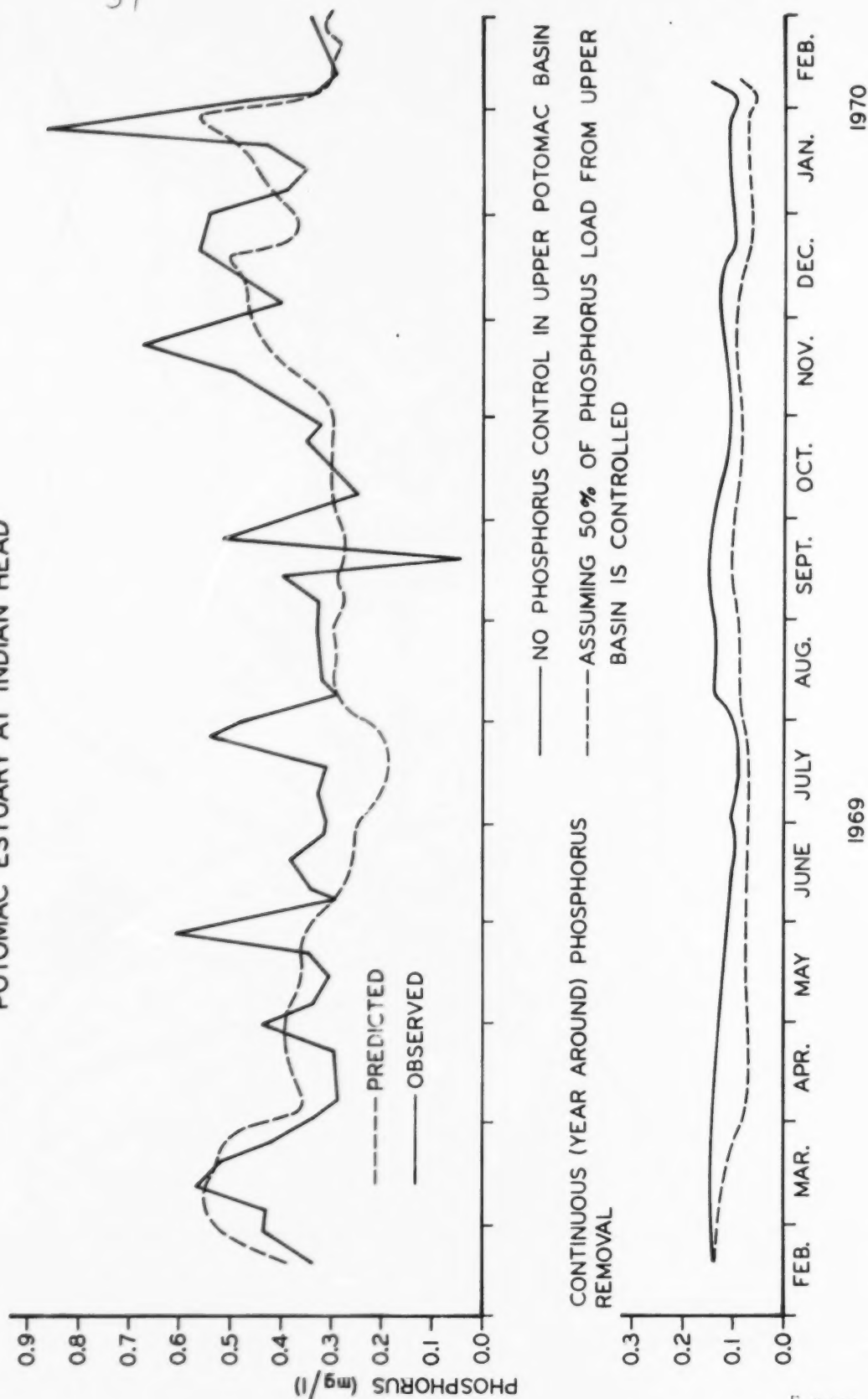
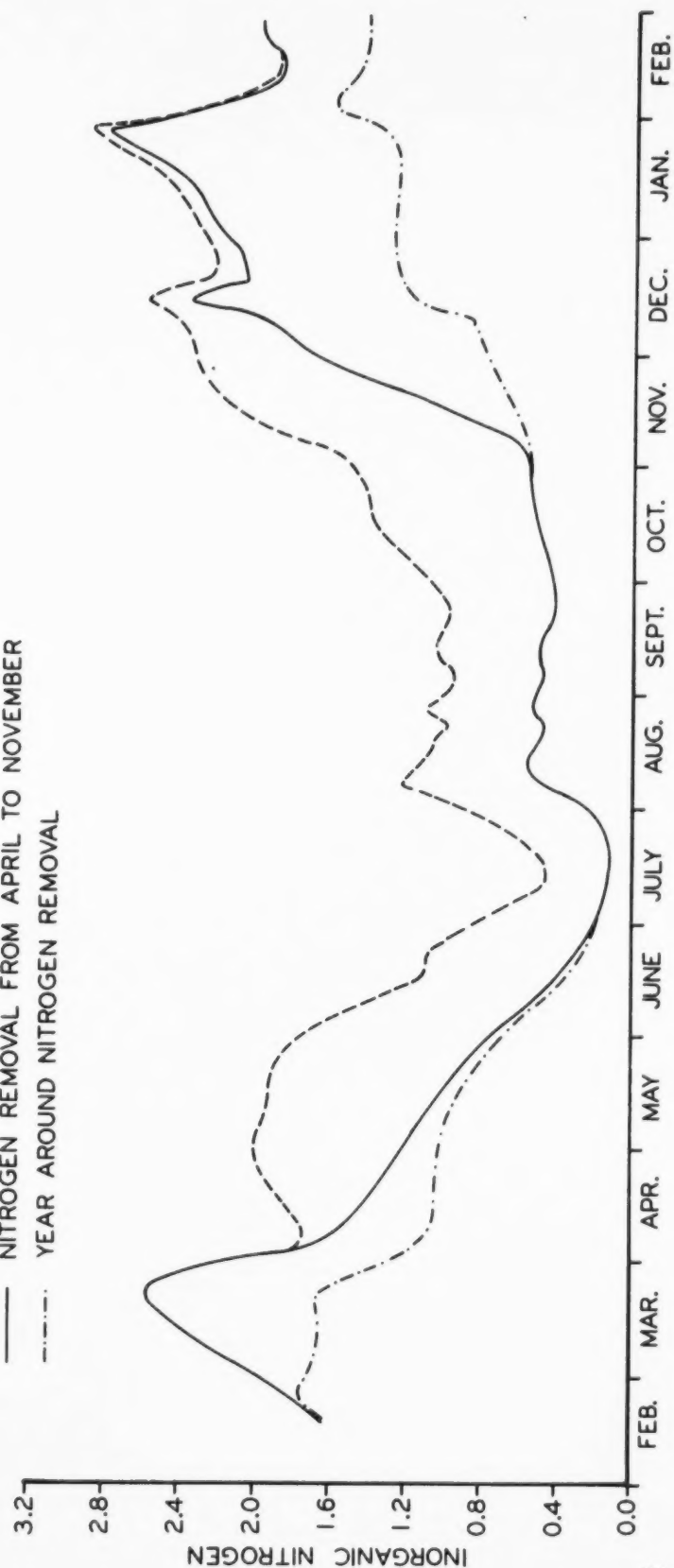


Figure 3

SIMULATED ANNUAL NITROGEN PROFILES

POTOMAC ESTUARY AT INDIAN HEAD

- NO NITROGEN REMOVAL
- NITROGEN REMOVAL FROM APRIL TO NOVEMBER
- - - YEAR AROUND NITROGEN REMOVAL



1969

1970

40

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